



Fermi National Accelerator Laboratory

TM-1666

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May 3, 1990

* Presented at the 1990 Conference on Computing in High Energy Physics, Santa Fe, New Mexico, April 9-13, 1990.



Operated by Universities Research Association Inc. under contract with the United States Department of Energy

DOE/ER/40085-20
Tufts University
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ABSTRACT

A workstation-based event display program for the Fermilab Tagged Photon Spectrometer (TPS) is described. Fast displays are required to monitor detector elements, observe hit patterns and energy deposition, and to check track reconstruction. Design considerations, novel features, and performance are described.

INTRODUCTION

The event display program used for E-769 at the TPS has been rewritten, primarily to speed it up. The initial program was written by Steve Bougerolle (Toronto) in 1986, extended to use the online event pool by Richard Milburn (Tufts), and later extensively modified by Ayla Kol (Yale) in 1987, prior to E-769 [1]. Their program used the Precision Visuals DI-3000 software library and ran on a VAX 11/780 at the TPS using a Lear-Siegler 7107 color graphics terminal. The program provided useful and attractive color displays of all the detector subsystems. However, a single display often took several minutes to complete and, since a full tape of 55,000 events could be written in less than 5 minutes, only a few events per tape could be monitored. The heavily-loaded VAX 11/780 and the Lear-Siegler terminal shouldered most of the blame, although the efficiency of DI-3000 was also questioned. The next TPS experiment, E-791, will distribute the VAX 11/780 computing load among a cluster of VAXstation 3200's, using their color displays to replace the graphics terminals. The event display software was rewritten to include a new user interface and to try to optimize performance of the program on the VAXstations, while retaining the DI-3000 graphics library. Speed improvement by a factor of 60 was obtained for some displays, and resulted in typical display times of less than one second on a VAXstation 3200.

TAGGED PHOTON SPECTROMETER

The TPS is described in numerous publications [2]. Briefly, the apparatus is a general purpose, two magnet spectrometer consisting of 23 silicon microstrip detectors (SMD's) near the target, 10 proportional wire planes (PWC's), 35 drift chamber planes (DC's), 2 multicell Čerenkov counters, electromagnetic (SLIC) and hadronic (Hadrometer) calorimeters, and two hodoscopes of scintillators for kaon and muon detection.

Additions for E-769 included the 10 PWC planes, four new planes of SMD's with 25 μm pitch (13 total), and the kaon scintillation counters. Beam particle identification was provided by a ring-imaging Čerenkov counter (DISC) to identify kaons and by a transition-radiation detector (TRD) to distinguish pions from kaons and protons. The 2.1% target contained 4 tungsten foils each 100 μm thick, and 3 copper, 5 aluminum, and 14 beryllium foils each 250 μm thick.

The final data set contained 500 million pion, kaon, and proton interactions from a 250 GeV/c sign-separated beam. Further details may be found in [3].

E-791 will run at the TPL during the next fixed-target running period. This experiment plans to write 9 billion events to tape and fully reconstruct 100,000 charm events. The new data acquisition system is capable of writing 20 times as fast as the system used in E-769. During the beam spill data will be stored in random access memory buffers (FIFO's). The data are then passed to Event Buffer Interface modules in VME crates, assembled by ACP microprocessors, and written to 8mm video tape. E-791 will have 6 new planes of SMD's downstream and 4 new planes upstream of the target (23 total). The beam momentum will be 500 GeV/c, giving an 80% increase over E-769 in the charm cross-section. E-791 expects to partially reconstruct about 700 beauty events, and to perform tests for a more extensive B physics experiment in a similar configuration.

MOTIVATION AND OBJECTIVES

The primary purpose of an online event display program is to monitor the performance of the spectrometer. For the TPS, the major subsystems include: (1) tracking elements, such as SMD's, PWC's, and DC's, (2) calorimeters, both electromagnetic and hadronic, and (3) particle identification elements, such as multicell Čerenkov counters, the TRD, and the DISC. One would like to examine hit patterns and energy deposition in these subsystems.

Another purpose is to study tracking, both during data acquisition and later as reconstruction proceeds. Tracks are useful to check alignment and to verify that the offline software is functioning properly. Tracks can be used to check the response of the particle identification subsystems and to provide vertex location and triggering checks. In addition, it is important to look at events which fail in track reconstruction and determine the cause of the failure. It is desirable to be able to display events from tape at every stage of the processing and to be able to read and list all data banks from within the display program. The present program was written with this goal in mind.

PROGRAM DESIGN CONSIDERATIONS

We assumed that an event display should be fast, easy to use, easy to modify (modular), available on various devices – workstations and terminals, layered on a device independent graphics package, such as GKS, DI-3000, PHIGS, or PEX, and finally, not dependent on a single high-priced workstation. The graphics package chosen was DI-3000, since this package is supported site-wide by Fermilab, provides drivers for many devices, has 3-D capability, and allows multiple windows, viewports, and workstations. The new program was intended primarily to be used on DEC VAXstations. These devices provide the familiar VMS operating system, good color 2-D graphics performance, and ability to edit code, debug, and run on similar workstations at many locations on the Fermilab site.

The next step was to improve the display speed. The most obvious limiting factor is the character transmission rate to the terminal. Most basic graphics terminals have a top speed of 19,200 or 38,400 baud. The TPS terminal server limited terminals to 9600 baud during E-769, or roughly 1,000 characters per

second. Some of the displays in the E-769 program required in excess of 45,000 characters, so it is easy to see that the image transmission time was a limiting factor for E-769. This was compounded by time-sharing on the heavily loaded VAX 11/780. The first priority was to add more CPU power and a fast graphics display. A VAXstation 3200 gave almost 3 times the CPU performance of the VAX, used the VMS operating system, and provided good color graphics. The next priority was to examine the existing program to see what DI-3000 commands used the longest character sequences. The commands identified were associated with: (1) software solid fill operations and (2) precision character text output. Solid fills can be removed or replaced with faster cross-hatched patterns. This is especially important if the display device does not support solid fill in hardware; even a black-and-white VAXstation 2000 can be quite slow. DI-3000 provides 48 pattern styles for software polygon fills. The choice of fill style is a trade-off between drawing speed and desired graphic effect, at least with low-end graphics devices. Text can be drawn in low-quality (string precision), medium-quality (character precision), or high-quality (stroke precision) by DI-3000. Drawing low-quality text, in a size large enough to be read unambiguously, gives large gains in speed. One can always include an option to switch to high-quality text if the user really wants a good hard-copy of a particular event. Similarly, solid fill can be enabled for special hardcopy and removed for general use.

A reduction in the number of subroutine calls can also improve performance. For example, a single polymarker command can be used to plot all the hits for the drift chambers, rather than using a single marker call repeatedly. Similarly, a single polyline command can be used to draw an energy deposition profile in a calorimeter, rather than using an individual one-channel histogram for each element.

Retained segments provide performance gains when a particular portion of the display is redrawn without change, provided the display device supports such local storage. VAXstations allow retained segments, while many basic graphics terminals do not. A test can be made when the event display program is loaded to see whether display list storage is supported. If it is not, retained segments may reduce performance due to additional transmission time of the repeated segments, and in this case it is better to use temporary segments and redraw the entire display. Retained segments are useful on VAXstations, particularly if the user wishes to scan the same view of many events to check some subsystem.

The Batch-of-Updates feature of DI-3000 may also be used to help optimize I/O. This is useful when a picture is built from many DI-3000 commands. Two subroutine calls, one just before the picture and one at the end, designate a Batch-of-Updates to allow DI-3000 to organize its I/O efficiently without concern for the intermediate stages of the picture.

COMMAND INTERFACE

The CERN program KUIP [4] was chosen as the user interface to the event display program. The reasons for this are: (1) it is a flexible interface containing many useful functions; (2) it contains both a command mode and a menu mode with extensive HELP features; and (3) it is already familiar to many high energy physicists since it is used as the interface to PAW [5]. KUIP has its

own compiler, KUIPC, which can be used to quickly and easily modify menus and define commands. The new event display program generates a main menu which lists submenus for KUIP, MACRO, and VECTOR commands, as in PAW, in addition to the graphics command menu, NED. The event display program does not use the HIGZ graphics interface, mainly because the 3-D interface to DI-3000 has not yet been specified. Presently, the alphanumeric KUIP menu includes the following commands: HELP, USAGE, MANUAL, EDIT, LAST, MESSAGE, SHELL, WAIT, UNITS, EXIT, QUIT, FUNCTIONS (submenu), ALIAS (submenu), and SET_SHOW (submenu).

Some of the KUIP commands deserve special attention. In particular, the SHELL command can be used to start an interactive subprocess from within the event display program. This allows, for example, file searches, queries about the state of the operating system, editing, and reading mail, before resuming operation of the event display program. The MANUAL command can be used to produce an entire user manual of all commands in TEX or LATEX format, with minimal user effort. Thus the program is easy to document and updates can be printed quickly in a very readable format. The ALIAS command allows the user to create his own command aliases to perform special functions, for example, the command:

```
ALIAS/CREATE LASER 'shell print/queue=fnal17.laser talaris.dat'
```

could be used to define a command called LASER which will send an event display output file named 'talaris.dat' to the laser printer.

The MACRO menu allows users to execute their own command files, consisting of KUIP or NED commands. One can also list macros, trace the command flow during macro execution, set or show macro attributes, and permit or restrict recursive macro execution. Macro files are given the extension '.kumac' just as in PAW. In particular, one can define a 'newlogon.kumac' file which will execute at the time the event display program is started to define useful aliases and execute a user-defined sequence of graphics commands before the initial display. Macros can also be written to provide a 'grand tour' of all the detector subsystems, proceeding one display at a time with a pause in between the displays.

The command menu for the new event display program (NED) contains:

1. WINDOW - Select a subsystem or region of interest.
2. VIEWS - Enter the number of views and names (X,Y,U,V,B,C).
3. DEVICE - Allows individual devices to be included/omitted.
4. OPTIONS - Select display options such as marker type, colors.
5. OUTPUT - A switch to turn additional workstations on or off.
6. CLEAR - Clear the screen and delete all retained segments.
7. LOOP - A switch to permit continuous display of new events.
8. SAME - Redisplay the same event.
9. NEXT - Display the next event, or skip a number of events.
10. ZOOM - Zoom in on a selected rectangular region of the display.
11. PN - Pan selected view of active window.
12. MAGNIFY - Enlarge or reduce the display window.
13. DEBUG - List banks, examine and recover from DI-3000 errors.

The WINDOW command specifies the world coordinate arguments of the desired region for display. This region varies from the scale of the SMD's (25 or 50 μm pitch) to the scale of the full spectrometer (20 meters not including beam line), a factor of 10^6 . It is therefore generally not useful or efficient to present all detector information on a single picture. A test on region number allows irrelevant details to be omitted from the display. For example, the individual SMD hits would not be visible on a display showing the DC hits. However, a ZOOM operation can redefine the world coordinate window and cause the SMD hits to be displayed if the zoom occurs on the SMD region. This feature makes the original display fast, but still gives access to full detail at each scale range. Recursive zooming is permitted, using a mouse click at two diagonal corners of a rectangle to define the new window each time. Currently there are seven predefined windows: ALL, R1, R2, R3, CAL, SMD, and CUSTOM. The 'Window ALL' command will display the full downstream spectrometer window, while R1, R2, and R3 refer to the regions before the first magnet, between the magnets, and after the second magnet. 'Window CAL' gives a calorimeter display and 'Window SMD' displays the SMD region. CUSTOM allows the user to specify numerically the diagonal corners of a window.

The VIEWS command allows simultaneous display of up to 4 different 'views' of the same event. For the tracking subsystems, this means a display of the hits in the devices which measure a specified coordinate such as X, Y, U, or V. Special views B and C give a display of the beamline components and the downstream Čerenkov counters respectively. For example, the command: 'VIEWS 4 X Y U V' will display the four possible tracking views. It is assumed that the WINDOW command has been called previously to specify the region of interest (e.g. SMD's or DC's).

Figure 1 shows an event from an E-769 Pass 2 tape. The display was generated using WINDOW ALL and VIEWS 1 X commands. The event header contains experiment number, run number, event number, number of tracks in the event, and the trigger bits, followed by the list of trigger types. Vertical lines represent DC's (11 planes in this view) and the boxes represent magnet apertures and the calorimeter sections. DC hits are drawn as X's. An option allows small boxes, with height equal to the drift cell size. Histograms show the energy deposition profiles in the front and back sections of the calorimeter. Tracks displayed in red were found during the SMD search. Tracks in green were found in the DC's only. Figure 2 shows the same view using the WINDOW SMD command. The SMD's are shown using O's to indicate hits, but not to scale. An option draws boxes of the actual strip size, but they are too small to be seen in this window. The 26 foils of the E-769 target are visible to the left, followed by the interaction scintillator (1/8 inch) and the 4 X-view SMD planes to the right. Four colors are used to identify the target foil types. Figure 3 shows the SMD window after a ZOOM command. The angular precision of the SMD's allows identification of the foil in which the interaction occurred, and the X and Z errors (3σ) are indicated by the size of the vertex box. Figure 4 shows a display of the C1 Čerenkov mirrors. Circles indicate the region of predicted light, assuming the tracks are pions. The relative amount of light measured in each ADC is given by the black vertical bar at the bottom of each mirror.

The DEVICE command is just a switch to allow selection of the items to be included in the displays. This feature is particularly useful in scanning a number of events to study response of a single device. 'Devices' include SMD's, DC's, PWC's, ADC profiles in the calorimeters, muon and kaon wall hits, tracks, magnet apertures, and the event header. The OPTIONS command provides some user control over marker types and colors. This is useful to adjust the displays for better visibility on different workstations.

The DEBUG command menu includes commands to (1) print a list of data types, (2) list event data, (3) list an individual data type, (4) list track data, (5) list vertex data, and (6) perform various DI-3000 commands to repair graphics damage in unusual situations. Examples of the latter include closing open segments, updating the display, closing a Batch-of-Updates, or initiating a new frame.

TIMING RESULTS

Extensive timing tests of the program have not yet been performed. However, a series of 40 events was displayed on several devices during periods of low system load. The devices included a Codonics terminal at 9600 baud connected to a VAX 8650, a VAXstation 2000 with color display, and a VAXstation 3200. The tests were run using a macro to read successive events on an E-769 Pass 2 output tape. Track reconstruction times are not included in the event display times. The average real times in seconds for single event displays are given in the following table, for several different views of each event.

TABLE I

Display	Codonics	VS2000	VS3200
SMD	7.7	2.2	0.55
ALL	13.	5.2	0.75
CER	44.	3.7	0.93

It is also of interest to determine whether VWS or DECwindows is faster on a given workstation. DI-3000 provides drivers for both graphics systems: GPV for VWS and XDW for DECwindows. A series of 160 events was displayed on a VAXstation 3200 running VWS with an average CPU time of 0.92 seconds per event; on a VAXstation 3500 running DECwindows, the CPU time was 0.87 seconds. The results are the same within errors, showing that either graphics system could be used. VWS is currently in use at the TPS, and will be used during E-791.

SUMMARY

The Fermilab E-769 online event display program was extensively rewritten to increase its speed and ease of use. It is a Fortran program using Precision Visuals DI-3000 package as the graphics interface to a VAXstation 3200 with color monitor. Performance was evaluated independently for the VWS and DECwindows software, using drivers provided by Precision Visuals. The DI-3000 interface allows the program to run on any graphics device for which a driver

is available, and also allows metafile storage of displays. The KUIP package [4] from CERN is used as the command interface. This provides the familiar menu interface used by PAW [5], gives extensive online HELP, prompts the user for additional input and inserts defaults if there are none, allows subprocesses to be spawned for editing or other DCL commands, and allows execution of user-written command macros. KUIP also simplifies modification of display commands, using the KUIPC compiler. Events are displayed by view (X,Y,U, or V vs. Z along beamline) and by window (range of the two chosen coordinates). Separate views are also provided for Čerenkov and beamline displays. Most display parameters may be adjusted from concise menus. Detector elements and hit displays can be made invisible to speed up the display or to reduce confusion. Zoom, pan, and magnify commands are available using the window definitions within DI-3000. Speed improvements were achieved with polymarker commands for hits, polyline commands for energy deposition profiles in the calorimeters, replacement of software characters with hardware characters, use of retained segments and device display lists, and code revisions to speed up certain calculations. Real times of about one second per view are considered acceptable for a complex event on a VAXstation 3200.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge many useful discussions with the members of the Fermilab Physics Software Projects group, particularly Harald Johnstad, Lee Roberts, and Eliane Lessner. Thanks are due to Fermilab, for partial support in 1988-9, and to Jeffrey Appel for the opportunity to work with the Fermilab Computing Department. This work was completed at Tufts University under contract DE-AC02-83ER40085 from the U.S. Department of Energy.

REFERENCES

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E769 R 1180 EV 344261 TK 11 TRG 11
PT/P ET

X VIEW

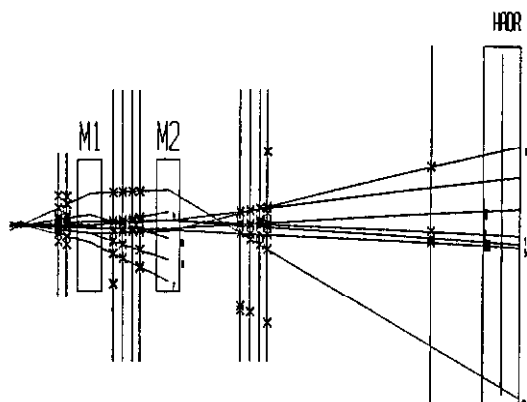


Fig. 1 X view of DC window.

E769 R 1180 EV 343675 TK 16 TRG 11
PT/P ET

X VIEW

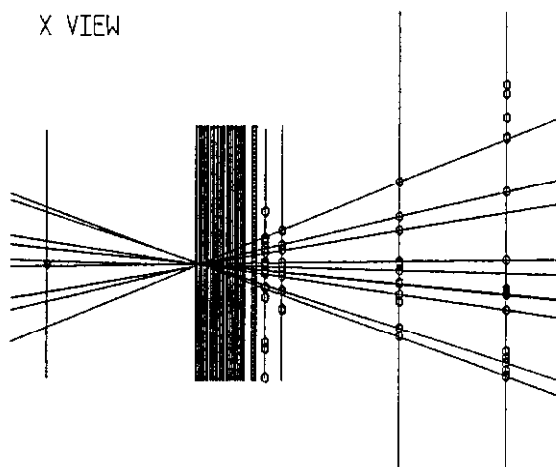


Fig. 2 X view of SMD window.

E769 R 1495 EV 795782 TK 8 TRG 9
TARG-INT

X VIEW

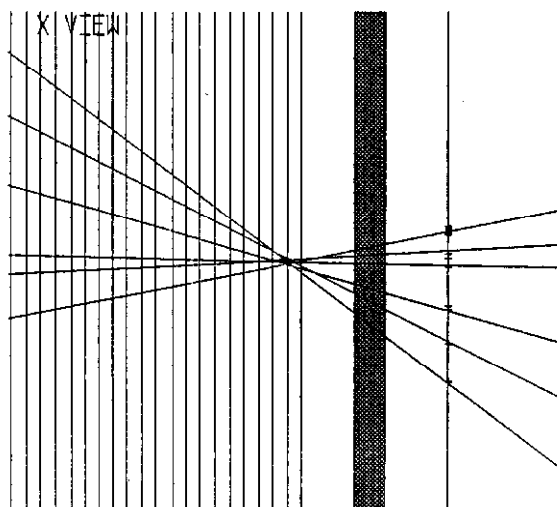


Fig. 3 Zoom on target region.

E769 R 1180 EV 344266 TK 6 TRG 12
DISC-K ET

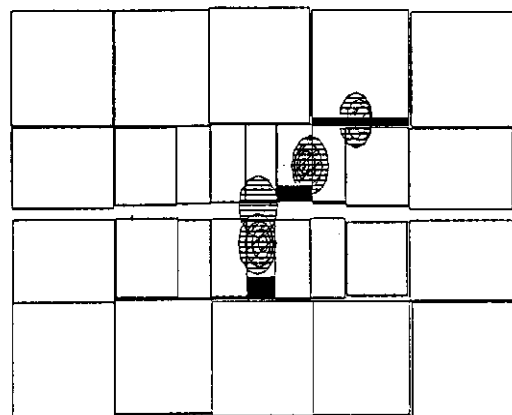


Fig. 4 Čerenkov counter display.